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Appendix

A Pseudocode of MNS Improvement Neighborhoods

```

01: Refresh Tabu List according to actual system time
02: Calculate decreasing cost ranking for als vehicle tours

03: WHILE (simulation_time < t.fixtime) {
04:   Identify feasible pair of vehicles for neighborhood operation, preferably a combination of a
05:   'cheap' and an 'expensive' vehicle tour, taking into account the Tabu list
06:   -> vehicle_a and vehicle_b
07:   Determine the exchangeable requests for vehicle_a and vehicle_b
08:   -> exchangeable_req_a and exchangeable_req_b
09:   Calculate the initial cost for the tours of vehicle_a and vehicle_b
10:   -> initial_cost
11:   Set best.cost = 999 999 999; best.tourroute_a = NULL; best.tourroute_b = NULL
12:
13:   FOR (i=0; i<exchangeable_req_a; i++) {
14:     FOR (j=0; j<exchangeable_req_b; j++) {
15:       IF (request i is compatible with vehicle B && request j is compatible with vehicle A) {
16:         Extract requests i and j from the tours of vehicle_a and vehicle_b, respectively
17:         Apply Best-Reinsertion for request i into tour B
18:         Apply Best-Reinsertion for request j into tour A
19:         Calculate the new cost for the tours of vehicle_a and vehicle_b
20:         -> new_cost
21:         IF (new_cost < best.cost) {
22:           best.cost = new_cost
23:           best.tourroute_a = new tour of vehicle A
24:           best.tourroute_b = new tour of vehicle B
25:         }
26:       }
27:     }
28:   }

29:   FOR (i=0; i<exchangeable_req_a; i++) {
30:     IF (request i is compatible with vehicle B) {
31:       Extract request i from the tour of vehicle_a
32:       Apply Best-Reinsertion for request i into tour B
33:       Calculate the new cost for the tours of vehicle_a and vehicle_b
34:       -> new_cost
35:       IF (new_cost < best.cost) {
36:         best.cost = new_cost
37:         best.tourroute_a = new tour of vehicle A
38:         best.tourroute_b = new tour of vehicle B
39:       }
40:     }
41:   }

42:   FOR (j=0; j<exchangeable_req_b; j++) {
43:     IF (request j is compatible with vehicle A) {
44:       Extract request j from the tour of vehicle_b
45:       Apply Best-Reinsertion for request j into tour A
46:       Calculate the new cost for the tours of vehicle_a and vehicle_b
47:       -> new_cost
48:       IF (new_cost < best.cost) {
49:         best.cost = new_cost
50:         best.tourroute_a = new tour of vehicle A
51:         best.tourroute_b = new tour of vehicle B
52:       }
53:     }
54:   }

55:   IF (best.cost < initial_cost) {
56:     Set tour of vehicle A = best.tourroute_a
57:     Set tour of vehicle B = best.tourroute_b
58:   }
59: }

```

Table 1: Pseudocode: λ -1 interchange (neighborhood I)

```

01: Calculate decreasing cost ranking for all vehicle tours
02: WHILE (simulation_time < t.fixtime) {
03:   Choose a vehicle, according to decreasing cost ranking
04:   -> current_vehicle
05:   Determine the exchangeable requests for current_vehicle
06:   -> exchangeable_requests
07:   Calculate the initial cost for the tour of current_vehicle
08:   -> initial_cost
09:   Extract the exchangeable requests from the vehicle's tour
10:   -> extracted_tour
11:   Generate all sequence permutations for possible re-insertion of the exchangeable requests
12:   -> permutations
13:   Set best_cost = initial_cost; best_tourroute = initial_tourroute
14:   FOR (i=0; i<permutations; i++) {
15:     Apply Best-Reinsertion of exchangeable_requests into extracted_tour
16:     in the sequence of permutation i
17:     -> new_tour
18:     Calculate the cost for new_tour of current_vehicle
19:     -> new_cost
20:     IF (new_cost < best_cost) {
21:       best_cost = new_cost
22:       best_tourroute = new_tour
23:     }
24:   }
25: }

```

Table 2: Pseudocode: intraroute optimal sequence (neighborhood II)

```

01: Calculate the current plan's objective value
02: -> initial_objective
03: Duplicate the current plan for back-up
04: -> initial_solution
05: Calculate decreasing cost ranking for all vehicle tours
06: Initialize a list all_exchangeable_requests
07: WHILE (simulation_time < t.fixtime) {
08:   FOR (i=0; i<number_of_vehicles; i++) {
09:     Choose most expensive vehicle, according to decreasing cost ranking
10:     -> current_vehicle
11:     Determine exchangeable requests for current_vehicle
12:     -> exchangeable_requests
13:     Append exchangeable_requests to the list all_exchangeable_requests
14:     Extract exchangeable_requests from current_vehicle's tour
15:   }
16:   WHILE (size of all_exchangeable_requests > 0) {
17:     Remove first request of all_exchangeable_requests
18:     -> first_request
19:     Apply Best-Reinsertion for first_request over all vehicle tours
20:   }
21:   BREAK
22: }
23: IF (Re-Insertion of all extracted requests was successful) {
24:   Calculate the new plan's objective value
25:   -> new_objective
26:   IF (new_objective > initial_objective) {
27:     Reconstruct initial solution
28:   }
29: }
30: ELSE {
31:   Reconstruct initial_solution
32: }

```

Table 3: Pseudocode: complete solution rebuild (neighborhood III)

B Parameterization - Detailed Results

Appendix B contains the detailed planning results of the parameterization process in Section 5.5.1. The adapted MNS procedure is applied to the real-life test scenario.

		b	
		empty travel time	delay
a		break/wait	operating time

		penalty cost "delay"							
		1		5		8		10	
penalty cost "traveling empty"	1	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-
	5	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-
	8	24133	221255	-	-	-	-	-	-
		465770	717746	-	-	-	-	-	-
	10	23246	243138	-	-	-	-	-	-
		465497	716586	-	-	-	-	-	-
	20	20281	350737	26135	139345	28174	118806	-	-
		467961	716086	484150	738128	487316	743333	-	-
	30	-	-	24246	170913	26805	144508	27424	128188
		-	-	485496	737585	489000	743648	489660	744927
	40	-	-	23355	195087	25364	161562	26278	143374
		-	-	485167	736366	488883	742091	490328	744449

Table 4: Parameterization of penalty costs (simulation speed $s = 5$, improvement neighborhoods I:II 66:33, anticipation horizon 10 min) - Detailed Results (in hours)

		penalty cost "delay"							
		1		5		8		10	
penalty cost "traveling empty"	1	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-
	5	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-
	8	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-
	10	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-
	20	-	-	26157	136544	-	-	-	-
		-	-	486986	740986	-	-	-	-
	30	-	-	24171	159541	26319	135305	27242	123891
		-	-	485833	737847	486831	740994	488387	743472
	40	-	-	22969	193705	24817	150976	-	-
		-	-	484724	735536	487621	740281	-	-

Table 5: Parameterization of penalty costs (simulation speed $s = 1$, improvement neighborhoods I:II 66:33, anticipation horizon 10 min) - Detailed Results (in hours)

		empty traveling	delay	break/wait	operating time
anticip. horiz.	5 min	24450	175323	485956	738249
	10 min	24246	170913	485496	737585
	30 min	24610	170142	488326	740780
	60 min	24545	173351	486564	738953
	90 min	24561	177846	485891	738295
	120 min	24591	187401	486199	738633

Table 6: Parameterization of anticipation horizon (simulation speed $s = 5$, improvement neighborhoods I:II 66:33, penalty costs (30,5)) - Detailed Results (in hours)

		empty traveling	delay	break/wait	operating time
anticip. horiz.	5 min	24193	162010	484880	736916
	10 min	24171	159541	485833	737847
	30 min	23966	158126	485019	736828
	60 min	23937	159509	485865	737646
	90 min	24076	168449	486213	738133
	120 min	24042	164628	485491	737377

Table 7: Parameterization of anticipation horizon (simulation speed $s = 1$, improvement neighborhoods I:II 66:33, penalty costs (30,5)) - Detailed Results (in hours)

		empty traveling	delay	break/wait	operating time
% I - % II	100-0	24455	164946	486402	738700
	75-25	24581	168246	488889	741313
	66-33	24246	170913	485496	737585
	50-50	24165	169027	487310	739317
	33-66	24579	177323	485439	737862
	25-75	24407	170408	486550	738800
	0-100	26193	220953	491455	745491

Table 8: Parameterization “allocation of improvement time” (simulation speed $s = 5$, anticipation horizon 10 min, penalty costs (30,5)) - Detailed Results (in hours)

		empty traveling	delay	break/wait	operating time
% I - % II	100-0	24008	154654	487019	738870
	75-25	24071	167129	486340	738254
	66-33	24171	159541	485833	737847
	50-50	24164	166108	484947	736955
	33-66	24081	161118	484747	736671
	25-75	24152	166242	485971	737966
	0-100	26055	214509	489198	743096

Table 9: Parameterization “allocation of improvement time” (simulation speed $s = 1$, anticipation horizon 10 min, penalty costs (30,5)) - Detailed Results (in hours)